STEREO TAPE RECORDER USING SILICON TRANSISTORS

By Larry Blaser

I. INTRODUCTION

The silicon-transistor tape recorder preamplifier described in this paper provides a bias signal and the necessary amplification and equalization for the record and play functions of a stereo tape recorder. The record amplifier has both high-level and low-level inputs with record equalization for tape speeds of 3-3/4 ips and 7-1/2 ips. Record bias and erase signals are supplied from a push-pull oscillator. Play equalization at 7-1/2 ips is the NAB standard and the 3-3/4 ips equalization is similar. Volume unit meters are included to monitor either the record inputs or the play outputs of the two channels. The circuit has been designed for a transport with three high-impedance heads. With minor changes it could be used with a two-head transport and/or with low-impedance heads.

A summary of the performance specifications using the Viking Model 86RMQ tape transport is given in Table I. Head specifications for the Viking Model 86RMS and more detailed performance data are included in Section III of the paper.

TABLE I

PERFORMANCE SPECIFICATIONS	
Play Frequency Response	20–20,000 cps within ±2 db of NAB equalization at 7-1/2 ips
Overall Record/Play Frequency Response	25–17,000 cps flat within ±3 db at 7-1/2 ips. 20–10,000 cps flat within ±3 db at 3-3/4 ips
Sensitivity	
Low-level Input	2 mV for "0" VU
High-level Input	200 mV for "0" VU
Amplifier Output	1 volt at "0" VU
Monitor Output	2 mV at 1 kc
1-kc Total Harmonic Distortion	1.5% at "0" VU
Signal-to-Noise Ratio	54 db measured with CCIF weighting characteristic and with a 1-kc signal at 2% total harmonic distortion
Bias Frequency	80 kc

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II. CIRCUIT DESCRIPTION

Play Amplifier

The play amplifier shown in the basic circuit schematic of Fig. 1 uses three very-high-gain, low-noise silicon planar transistors, type SE4001. The input stage has sufficient emitter degeneration for low total harmonic distortion (about 0.2% with a 2 mV input from the play head). Signal-to-noise ratio of the input stage, with Q_1 biased at I_C = 50 μA and with the 700 mh play head, is sufficiently high so that the overall signal-to-noise ratio is limited only by tape hiss. The circuit of transistors Q_2 and Q_3 is a high-input-impedance, low-output-impedance feedback amplifier. Play equalization is determined in this amplifier by the frequency selective feedback networks; R_1, R_3 and C_1 for 7-1/2 ips equalization and R_1, R_2 and C_1 for 3-3/4 ips equalization. The collector of Q_3 drives the volume unit (VU) meter and the amplifier output through a voltage divider. For a sine wave, "0" on the VU meter corresponds to a 1-volt signal at the amplifier output.

Record Amplifier

The record amplifier, which uses the three transistors of the play amplifier by a switching arrangement, plus two additional SE4001 transistors, is shown in the basic circuit schematic of Fig. 2. Q_1 is used as an amplifier for low-level inputs. High-level inputs are introduced into the collector of Q_1 through a 120 KΩ resistance and are added to amplified low-level inputs. The circuit of Q_2 and Q_3 is a flat amplifier which drives the VU meter, the record equalization circuit of Q_4 and Q_5, and also supplies an audio output for monitoring the record input signals. As in the play amplifier, a 1-volt sine wave signal at the amplifier output corresponds to "0" on the VU meter.

The network R_4, R_5, and C_2 in the base of the amplifier Q_5 provides a boast below 50 cps. Capacitor C_3 rolls off the input response above 20 kc. Above 1 kc, the reactance of C_5 (and C_6) in the emitter of Q_5 increases the gain of Q_5. At about 20 kc, C_5 (and C_6) and the coil L_1 are series resonant for maximum high frequency boast.

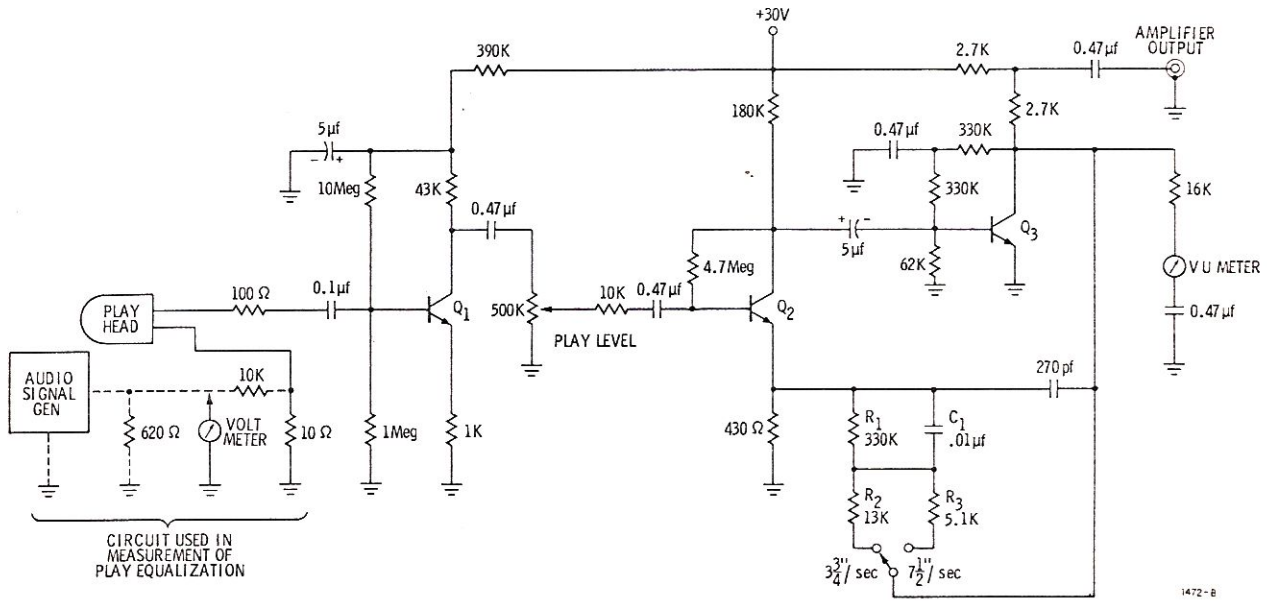


FIG. 1. Basic circuit of play amplifier.

At 38 kc, the subcarrier frequency of FM multiplex, the reactances of components L_1 and C_4 are near parallel resonance. This raises the impedance in the emitter of Q_5 and rejects multiplex subcarrier signals. Otherwise, if the subcarrier were of sufficient amplitude at the record input, the second harmonic would beat with the bias frequency to produce audible recorded signals.

Transistor Q_4 supplies d-c collector current to Q_5 but it is a high impedance to a-c so that all of the audio signal current from the collector of Q_5 flows in the record head.

The parallel filter, C_7 and L_2, isolates the bias signal from the record amplifier. This is necessary as the high impedance record head requires a bias current which produces a 45-volt peak-to-peak bias voltage across the head. If this were not rejected from the amplifier output, severe clipping would result. For lower impedance record heads, the bias voltage would be less, thereby eliminating the need for the filter. An adjustable bias signal is supplied to the record head through R_6 and C_8.

Bias Oscillator

The erase and bias signals are generated by the 80-kc push-pull oscillator shown in the basic circuit schematic of Fig. 3. With this symmetrical drive arrangement, even order harmonics, which deteriorate the signal-to-noise ratio, are less than one percent of the oscillator output. A neon lamp indicates oscillator operation in record positions.

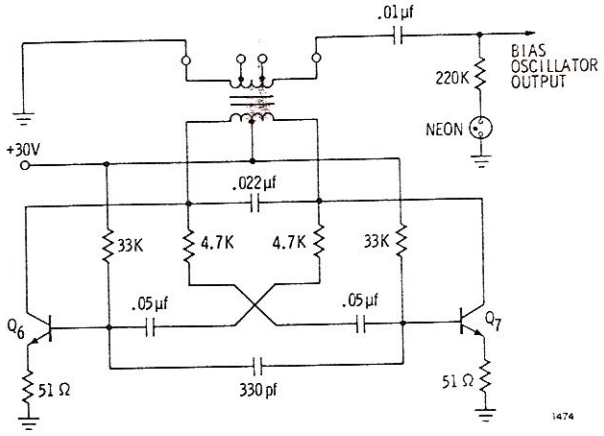


FIG. 3. Basic circuit of bias oscillator.

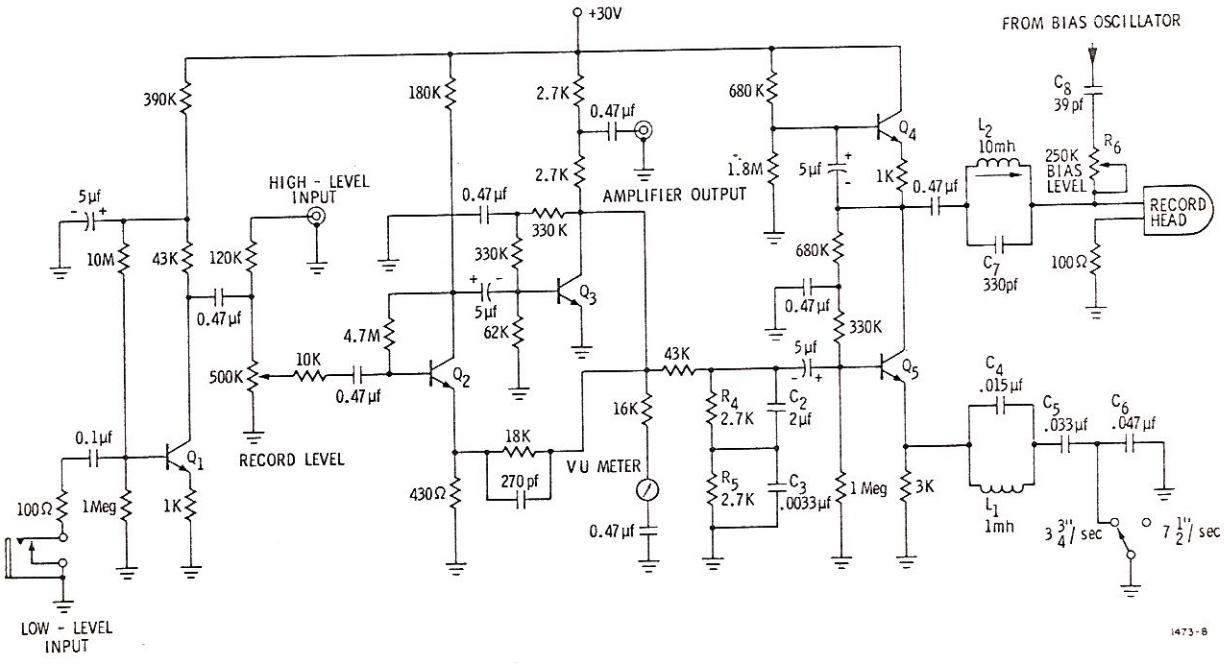
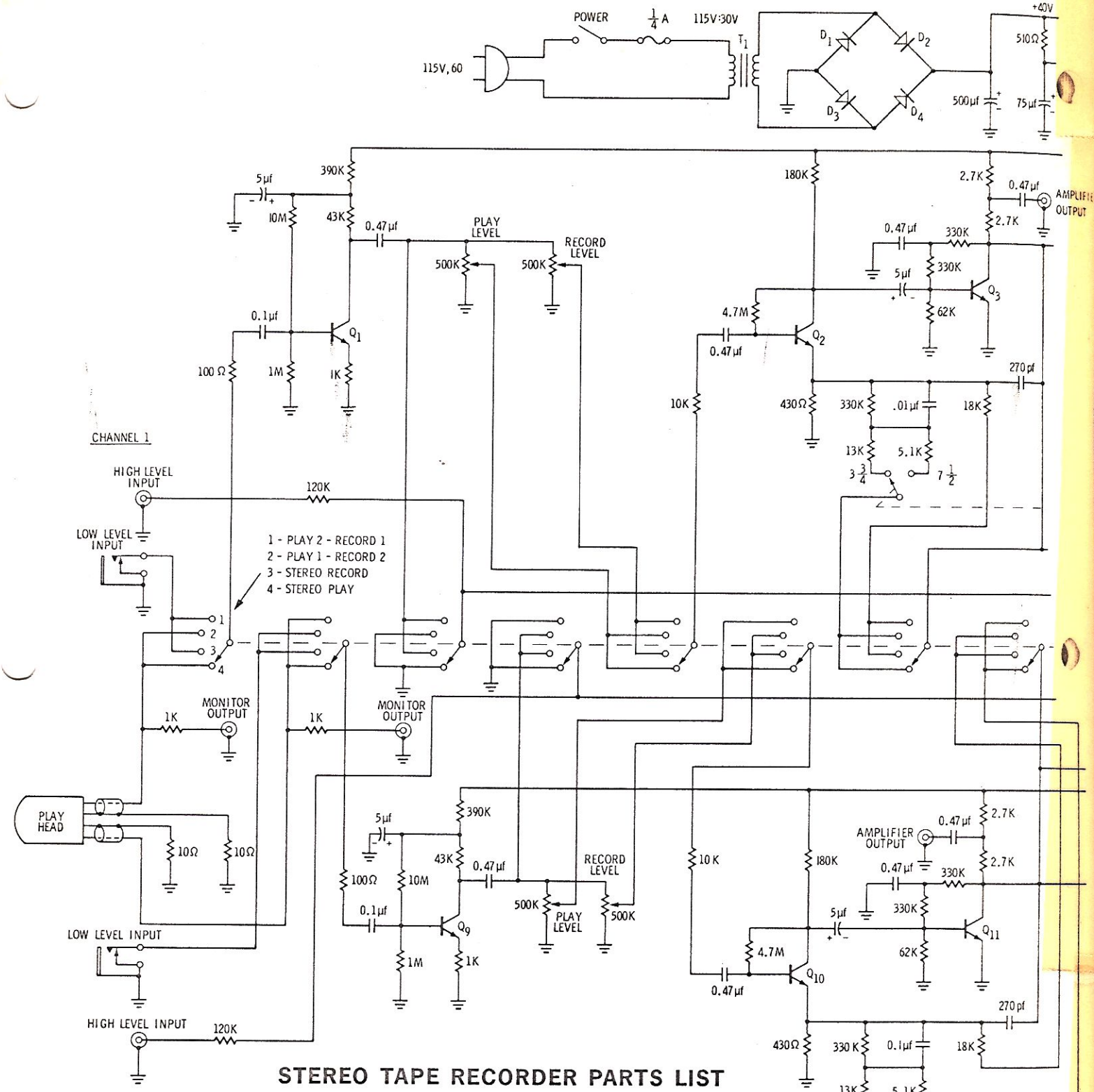


FIG. 2. Basic circuit of record amplifier.



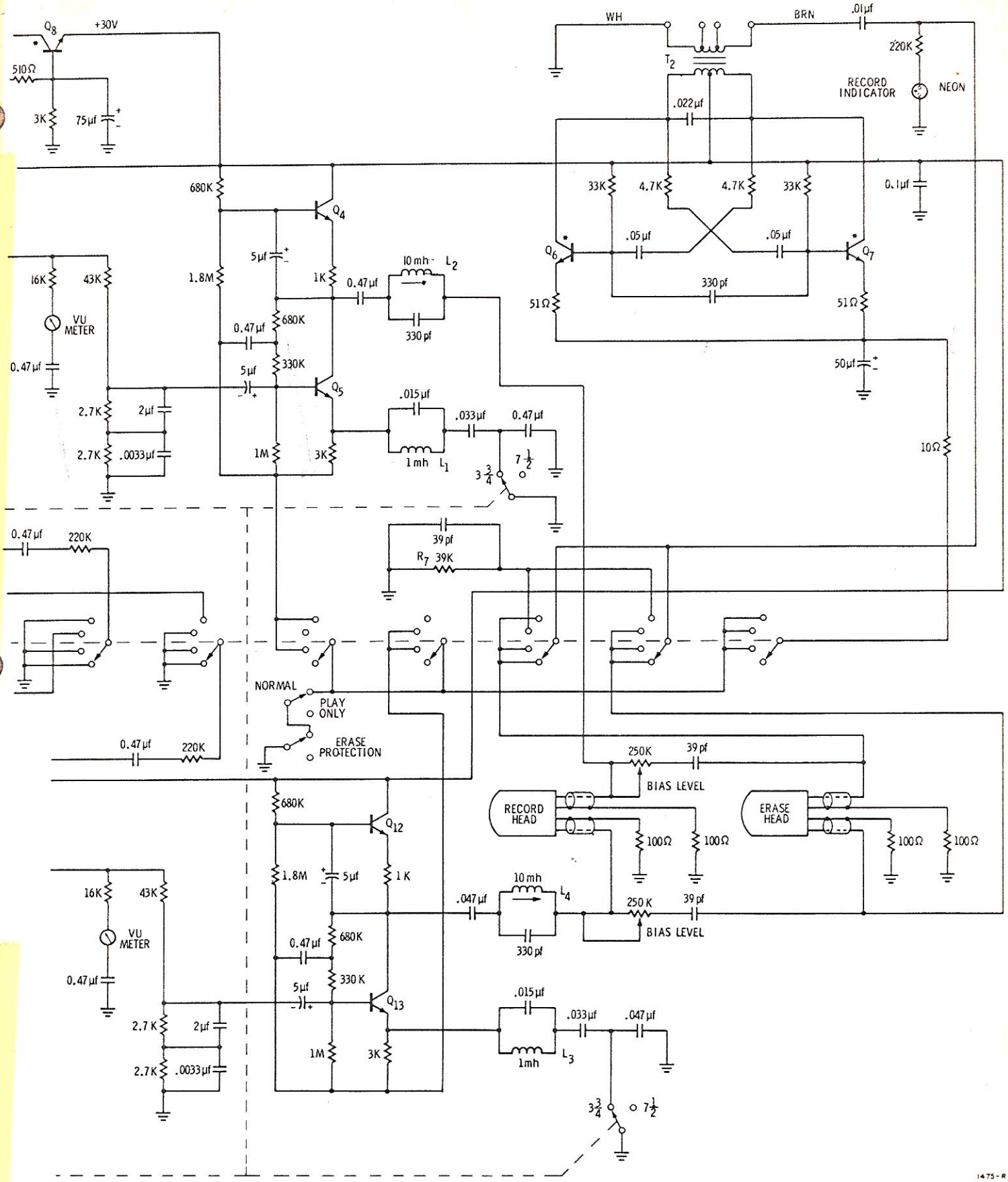
STEREO TAPE RECORDER PARTS LIST

CHANNEL 2

* HEAT DISSIPATOR REQUIRED

D_1, D_2, D_3, D_4	FD200.
Q_1 to Q_5, Q_9 to Q_{13}	Fairchild entertainment type SE-4001.
Q_6, Q_7	2N699.
Q_8	2N2297 or SE8001.
L_1, L_3	1 mh RFC, National Radio Co., Type R50-1 or equivalent.
L_2, L_4	10 mh coil, Miller 1355 or equivalent.
T_1	Triad F91X or equivalent.
T_2	Nortronics Type T60-T2 or equivalent.

FIG. 4. SCHEMATIC DIAGRAM


Q8
+30V
510Ω
3K
75μf
WH
BRN
.01μf
T2
220K
RECORD INDICATOR
NEON
.022μf
680K
Q4
33K
4.7K
4.7K
33K
0.1μf
.05μf
.05μf
Q6
Q7
330 pf
51Ω
51Ω
50μf
16K
43K
VU METER
0.47μf
5μf
1.8M
1K
0.47μf
10 mh
L2
330 pf
0.47μf
680K
5μf
330K
Q5
2.7K
2μf
2.7K
.0033μf
1M
3K
.015μf
.033μf
0.47μf
1 mh
L1
7½
3¾
10Ω
39 pf
R7 39K
0.47μf
220K
NORMAL
PLAY ONLY
ERASE PROTECTION
0.47μf
220K
250K
39 pf
BIAS LEVEL
RECORD HEAD
ERASE HEAD
100Ω
100Ω
100Ω
100Ω
680K
Q12
1.8M
5μf
1 K
16K
43K
VU METER
0.47μf
10 mh
L4
.047μf
250 K
39 pf
BIAS LEVEL
330 pf
0.47μf
680K
5μf
330 K
Q13
.015μf
.033μf
.047μf
2.7 K
2μf
2.7K
.0033μf
1M
3K
1mh
L3
3¾
7½
1475-R

Complete Recorder Circuit

The complete recorder schematic which includes provisions for switching between play and record, either stereo or monaural and also allows sound-on-sound recording is shown in Fig. 4. When a channel is in play, the record circuitry is disabled by removing its ground. In stereo play, the ground for the bias oscillator is removed. Because the bias oscillator supplies both channels, in monaural record the bias oscillator output is removed from the other channel. A dummy load, R_7 and C_9, duplicates the normal load to maintain constant frequency and output amplitude of the bias oscillator.

The +30 volt supply for the recorder uses a single transistor, Q_8, in a ripple reduction circuit.

III. PERFORMANCE

The Viking Model 86RMQ tape transport and Scotch Magnetic Tape, type 1/4-150-18 were used in obtaining performance specifications on the recorder preamplifier.

Head Characteristics

The head characteristics of the Viking Model 86RMQ tape transport are given in Table II. This transport with the accompanying heads was used in the design and evaluation of the recorder preamplifier. Other heads, with appropriate circuit changes and other quality tape transports could be used with comparable performance.

TABLE II

VIKING MODEL 86RMQ HEAD CHARACTERISTICS
(Description taken from manufacturer's specifications)

Quarter Track In-Line Stereo Play Head	
Gap width	0.00009 inch
Track width	0.043 inch
Impedance at 1 kc	4.5 KΩ
Nominal inductance	700 mh
D-c resistance	380 Ω
Play output at 1 kc	2 mV
Quarter Track In-Line Stereo Record Head	
Gap width	0.00025 inch
Track width	0.043 inch
Impedance at 1 kc	1.8 KΩ
Audio current for recording	0.035 mA
Recording bias current	0.25 to 0.35 mA
Nominal inductance	275 mh
D-c resistance	260 Ω
Quarter Track In-Line Stereo Erase Head	
Gap width	0.004 inch
Track width	0.062 inch
Impedance at 60 kc	30 KΩ
Erase current	3 to 4.5 mA
Nominal inductance	80 mh
D-c resistance	270 Ω
Erase efficiency	60 db

Play Frequency Response

The measured play responses at 7-1/2 ips and at 3-3/4 ips are shown in Fig. 5. These curves, taken from measurements of the circuit of Fig. 1, include the capacitive peaking of the play head at slightly below 20 kc. The 7-1/2 ips response is within ±1 db of the standard NAB tape equalization between 50 cps and 20 kc, and within ±2 db between 20 cps and 20 kc. The 3-3/4 ips equalization introduces less attenuation than the NAB equalization above 1 kc thereby partially compensating for the reduced high frequency head output at the slower tape speed.

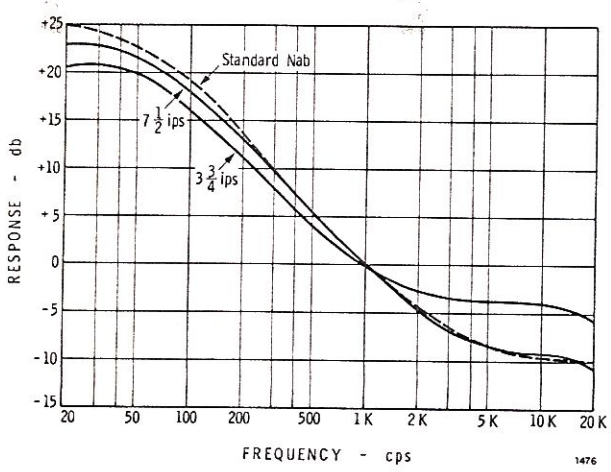


FIG. 5. Play equalization.

Record Equalization

The record equalization provides a boast at the high frequencies to compensate for lower head efficiency above 1 kc and a boast at low frequencies to match the low-frequency roll-off in the play equalization. Above 20 kc, the response cuts off rapidly for rejection of the subcarrier components in FM multiplex signals. The equalization responses shown in Fig. 6 were taken by measuring the current in the record head with a constant amplitude signal applied at the high-level input.

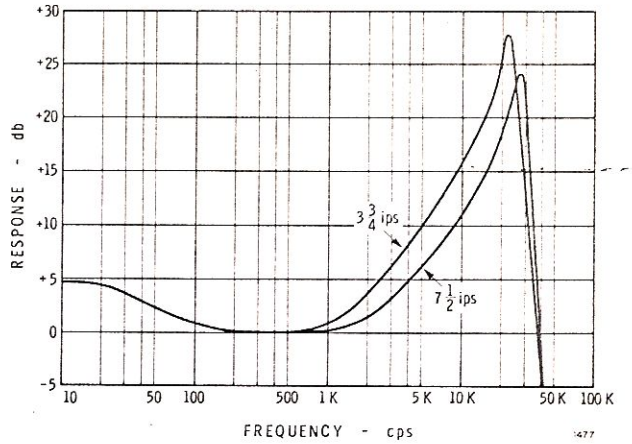


FIG. 6. Record equalization.

Input Impedance

The input impedance of the low-level input is primarily dependent upon the h_{fe} of the input transistor. With an h_{fe} of 200 at the collector current, I_C = 50 μA, the input impedance is about 250 KΩ. The high-level input impedance is 150 KΩ.

Output Impedance

Because of the low impedance at the collector of Q_3, the amplifier output impedance of 1.4 KΩ is essentially the parallel combination of the divider resistors in the collector of Q_3. The monitor output impedance is the impedance of the play head, which, for the head used, is 4.5 KΩ at 1 kc.

Overall Frequency Response

Overall frequency response shown in Fig. 7 was taken at a signal level 10 db below "0" VU. The small amplitude variations below 500 cps are due to contour effects associated with the play head and are difficult to compensate for electronically. The high frequency response is determined by a number of factors which include record and play equalization, head and tape characteristics, and bias and record levels. The bias level was set for approximately 2 db of "over-bias" for a 1-kc signal recorded at 7-1/2 ips at a level of "0" on the VU meter.

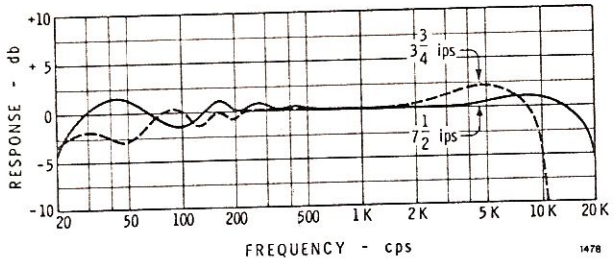


FIG. 7. Overall record/play response.

Sensitivity

All sensitivity measurements were made with the volume controls at maximum.

Play head output at 1 kc for "0" VU	2 mV
Low-level input for "0" VU	2 mV
High-level input for "0" VU	200 mV
Amplifier output at "0" VU	1 Volt
Amplifier output in play for signal recorded at "0" VU	1 Volt
Amplifier output in play using an Ampex test tape	1.2 Volts

Total Harmonic Distortion

Measured 1 kc total harmonic distortion versus record level is shown in Fig. 8. A record level of 0 db corresponds with "0" VU.

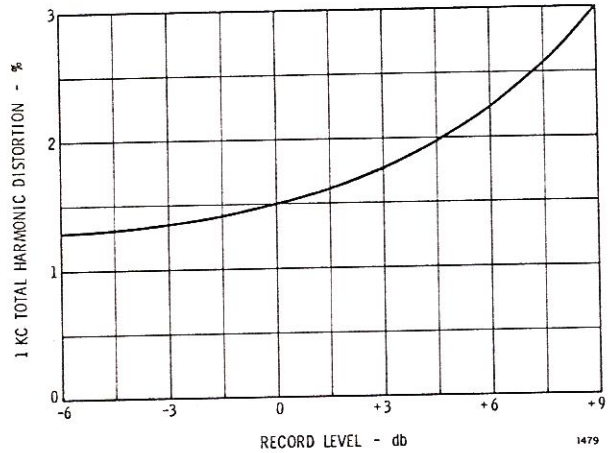


FIG. 8. 1 kc total harmonic distortion versus record level.

Signal-to-Noise Ratio

Signal-to-noise ratio is a measure of the ratio of the objectionable noise signal appearing at the amplifier output to a reference output signal. To properly measure objectionable noise, a weighting function is required which represents the loudness response versus frequency of the ear at low signal levels and also accounts for the listeners greater objection to noise in certain portions of the audio spectrum. Such a function is not easy to obtain and is subject to individual differences. However, the CCIF weighting characteristic was developed for this purpose and has found wide acceptance in Europe.* This curve, shown in Fig. 9, has been used in signal-to-noise ratio measurements of the recorder. Less meaningful measurements were also taken with simple bandwidth restrictions. In all measurements the signal was taken at 1 kc with the level a function of total harmonic distortion.

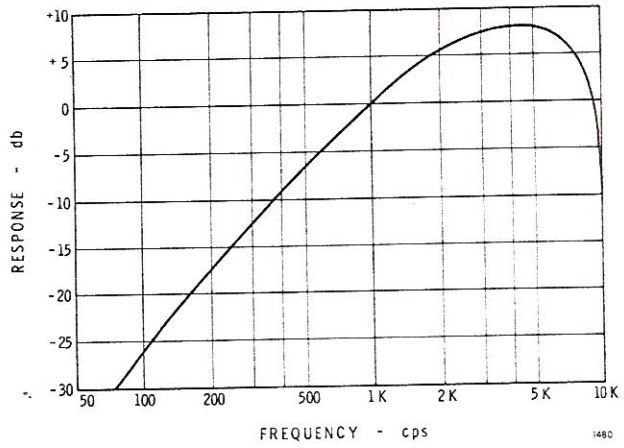


FIG. 9. CCIF weighting characteristic for noise measurement.[1]

The signal-to-noise ratios are given in Table III for various bandwidth restrictions, signal amplitudes, and the following three conditions of the play head:

(1) Erased tape passing over the play head at 7-1/2 ips

(2) Virgin tape passing over the play head at 7-1/2 ips

(3) No tape on play head.

* CCIF-Comite Consultatif International des Frequences (International Consulting Committee on Frequency).

TABLE III

SIGNAL-TO-NOISE RATIO MEASUREMENTS

Condition at Play Head	Bandwidth Restriction*	1 kc Signal Reference Level "0" VU 1.5% Total Harmonic Distortion	+5 db 2% Total Harmonic Distortion	+9 db 3% Total Harmonic Distortion
Tape erased at 80 kc over head at 7-1/2 ips	20 cps to 20 kc	38 db	43 db	47 db
	100 cps to 10 kc	46 db	51 db	55 db
	200 cps to 10 kc	51 db	56 db	60 db
	CCIF	49 db	54 db	58 db
Virgin tape over head at 7-1/2 ips	20 cps to 20 kc	39 db	44 db	48 db
	100 cps to 10 kc	50 db	55 db	59 db
	200 cps to 10 kc	57 db	62 db	66 db
	CCIF	55 db	60 db	64 db
No tape on head	20 cps to 20 kc	39 db	44 db	48 db
	100 cps to 10 kc	51 db	56 db	60 db
	200 cps to 10 kc	63 db	68 db	72 db
	CCIF	62 db	67 db	71 db

*Bandwidth restriction frequencies indicate settings of the Kron-Hite Model 310-ABR filter which was used to determine the bandwidth except for the CCIF characteristic. The CCIF bandwidth restriction was determined with a special network which duplicated the CCIF curve shown in Fig. 9.

Bias Oscillator

The harmonic content in the 80 kc bias oscillator output and in the bias and erase currents are given in Table IV.

ACKNOWLEDGMENT

The author extends his thanks to Earl L. Cummins for his helpful design suggestions, and to Donald L. Smith for his careful work in the construction of the recorder.

Reference

1. Hanswerner Pieplow, "Signal to Noise Ratio and Equalization of Magnetic-Tape Recording," I. R. E. Transaction on Audio, March-April 1962.

TABLE IV

HARMONIC COMPONENTS IN BIAS AND ERASE SIGNALS

Harmonic Frequency	Oscillator Output Terminated in 20 KΩ Resistive Load (normal load removed)	Oscillator Output in "Stereo Record"	Erase Current in "Stereo Record"	Bias Current in "Stereo Record"
Fundamental	0 db	0 db	0 db	0 db
2nd	-47 db	-45 db	-55 db	-46 db
3rd	-38 db	-36 db	-28 db	-35 db
4th	-56 db	-60 db	-70 db	-50 db
5th	-53 db	-57 db	-42 db	-60 db
6th	-57 db	-51 db	-47 db	-45 db
7th	-55 db	-50 db	-53 db	-49 db
8th	-61 db	-58 db	-48 db	-57 db
9th	-70 db	-70 db	-54 db	-64 db
10th	-64 db	-59 db	-60 db	-52 db